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Bonding Requirements for Natural Gas Producers

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Abstract

Natural gas producers are constantly making tradeoffs between money, time, and environmental risk. The private costs and benefits of drilling are realized immediately, but the external costs are not. By the time external costs are well understood, producers may no longer exist or may not have the resources to finance necessary cleanups or to compensate those who have been affected. This well-known "judgment proof problem" means that producers do not face the total cost of potential external damages, and thus may take too many risks. This article discusses alternative regulatory approaches for mitigating moral hazard in natural gas production. Particular emphasis is given to bonding requirements, which have tended to receive less attention than the other approaches but have a long history. There are important limitations with bonding, but in some ways this approach is actually quite well-suited to many of the environmental risks in this market. (JEL: K32, L71, Q48, Q58)

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1. Introduction

Hydraulic fracturing and other recent technological advances have dramatically increased the availability of natural gas. After peaking in 2008, U.S. natural gas prices have fallen dramatically and industry analysts are forecasting that prices will remain low for the next several decades. This increase in the supply of natural gas has broad implications for energy markets in the United States and abroad. Energy is a key input in virtually all sectors of the economy, and inexpensive natural gas is good for growth. Natural gas is also less carbon-intensive than other fossil fuels, leading some to describe the fuel as the "blue bridge to a green future."

At the same time, these new forms of natural gas production raise a number of potential environmental concerns. There are serious concerns, in particular, about potential contamination of groundwater and about the increased scope for large-volume surface spills. The U.S. Environmental Protection Agency (EPA) and other organizations are working to better understand the potential risks to human health and the environment, but it will be years before comprehensive analyses are available.

Although the scope for environmental damages is still poorly understood, it is not too early to examine the underlying *incentives* faced by producers. Natural gas producers are constantly making tradeoffs between money, time, and environmental risk. The private costs and benefits of drilling are realized immediately, but the external costs are not. By the time external costs are well understood, producers may no longer exist or may not have the resources to finance necessary cleanups or to compensate those who have been affected. This well-known "judgment proof problem" means that producers do not face the total cost of potential external damages, and thus may take too many risks.

This article discusses alternative regulatory approaches for mitigating moral hazard in natural gas production. The discussion draws heavily on the broad existing literature in law and economics, and specifically, on the economic analysis of accident law. One of the over-arching themes in these previous analyses is the inability of any single policy to yield the socially desirable level of care. Direct regulation is imperfect because monitoring is costly. The tort system requires less monitoring, but is limited by bankruptcy protection laws. And mandated insurance can help ensure that funds are available to pay for cleanups, but does not correct the underlying moral hazard problem.

After discussing these three regulatory approaches, the article then turns to focus on bonding requirements as an important additional policy tool. Bonding has tended to receive less attention than the other approaches, but has a long history in this market. Natural gas producers drilling on U.S. federal lands have been required to post bonds since the 1920. There are important limitations with bonding, but in some ways this approach is actually quite well-suited to many of the environmental risks in this market and can be a valuable complement to the other regulatory approaches.

This article focuses on risks to groundwater, surface water, land contamination, and on site reclamation when production has been completed. The discussion will have little to say on air pollution or greenhouse gas emissions. Scientists have raised concerns, for example, about "fugitive" methane emissions during hydraulic fracturing (Tollefson 2012). This has large potential implications for the environment, but is fundamentally quite different from these other types of damages because it cannot be observed *ex post*. Once a well has been constructed, it is essentially impossible to determine what air pollutants or greenhouse gases have been released. Bonding requirements, mandated insurance, and the tort system all hinge on damages being *observable* so these approaches are poorly suited to the air and greenhouse gas impacts.

The paper proceeds as follows. Section 2 provides background information, briefly laying out the prospects and challenges introduced by shale gas and other unconventional sources of natural gas. Section 3 outlines the moral hazard problem and discusses the first three regulatory approaches. Section 4 then turns to bonding requirements, reviewing existing federal and state requirements and discussing the key issues in policy design. Section 5 offers concluding comments.

2 Background

Shale gas and other unconventional sources of natural gas offer tremendous potential benefits for the U.S. economy, but they also pose important environmental risks. This section begins with a brief discussion of hydraulic fracturing (“fracking”) and its implications of the U.S. economy. The section then outlines some of the environmental risks, with emphasis on how decisions by producers can influence the probability of accidents.

2.1 Prospects for Natural Gas

Natural gas producers have long known that shale and other rock deposits contain large amounts of natural gas, but only recently did it become possible to access these reserves cost-effectively. Hydraulic fracturing is made possible by the combination of two technologies. First, improvements in horizontal drilling techniques now allow drillers to control drilling operations thousands of feet below the earth’s surface. Second, computer applications can map these underground resources with a high degree of detail.

Unconventional natural gas sources, including shale gas, coal-bed methane, and “tight” gas sands today represent more than half of U.S. natural gas production. Looking to the future, shale gas is probably the most important of the three. Virtually non-existent just a few years ago, shale gas has grown to represent 23 percent of all U.S. natural gas production and is forecast to more than double by 2035 and make up almost half of total U.S. production (U.S. DOE 2013a).

This dramatic increase in the supply of natural gas has broad implications for energy markets in the United States and abroad. Since 2008, U.S. natural gas prices have fallen dramatically and, as of January 2014 are at less than one-third the level that was observed at the peak in 2008. Figure 1 plots natural gas prices from 1990 to 2012, with predicted prices through 2035. DOE (2013a) predicts that natural gas prices will remain low for the next two decades.

Low prices mean that natural gas has become the dominant choice in many sectors of the U.S. economy. Even before the recent price decreases, natural gas was the overwhelming choice for residential and commercial heating. In addition, natural gas has become the fuel of choice for investments in new electricity generation. At current natural gas prices, the total lifetime cost of electricity from combined-cycle natural gas plants is $67 per megawatt hour, compared to $100 for coal, and even more for renewable forms of electricity generation such as wind and solar (DOE 2013b). Natural gas is becoming increasingly important to industrial customers as well.

The increase in the supply of natural gas also has important implications for the environment. Natural gas is less carbon-intensive than other fossil fuels. For example, in electricity generation natural gas plants emit about half the carbon dioxide emissions of coal per unit of generation. The differences are even greater for criteria pollutants such as sulfur dioxide, nitrogen oxides, and particulates. Muller, Mendelsohn, and Nordhaus (2011) calculate that the external costs from criteria pollutants of natural-gas–fired electricity generation are about one-thirtieth the size of the external costs of coal-fired electricity generation.

2.2 Potential Environmental Risks

These new forms of natural gas production also raise a number of potential environmental concerns. There are important concerns, in particular, about potential contamination of groundwater and about the increased scope for large-volume surface spills. These risks are still poorly understood. While it is true that hydraulic fracturing has been performed for many years, the techniques are evolving rapidly enough that it is difficult to make strong statements based on the historical record.

2.2.1 Risks to Groundwater

One of the most often discussed categories of environmental risks is groundwater contamination. The value of groundwater resources is extremely high, so these concerns merit close attention even when the underlying level of risk for a given project is low. There is also beginning to be empirical evidence examining possible links between natural gas drilling and groundwater contamination (see, e.g., Osborn et al. 2011 and

Warner, et al. 2012).

To understand how groundwater contamination might occur, it is helpful to briefly describe the well construction process. Shale gas and other unconventional natural gas resources are accumulations of natural gas trapped within rock or sand formations with low permeability. Conventional natural gas fields, in contrast, are large, open reservoirs of natural gas. Whereas conventional natural gas resources can be extracted using vertical wells, shale gas reserves usually require horizontal drilling and hydraulic fracturing. The objective of hydraulic fracturing is to open these rock or sand formations and create pathways through which natural gas can move.

Drilling a well consists of several steps. The producer first drills a shallow well, lines the well with steel pipe (casing), and then cements the pipe by pumping cement between the casing and the wellbore wall. This process of drilling, casing, and cementing is repeated several times at progressively lower depths. These first steps are critical from an environmental perspective because it is only at these shallow depths (less than 1,000 feet) that groundwater is present. The drilling turns horizontal once the target zone has been reached. For shale gas this typically occurs between 5,000 and 10,000 feet. At this point hydraulic fracturing is performed. The producer injects large quantities of water, sand, and chemicals at high pressure into the horizontal well to break apart rock and sand formations, opening pathways through which the natural gas can move.

Throughout well construction there is scope for producer behavior to influence the probability of accidents. Casing and cementing have been used for decades, and most producers are experienced in these techniques, but they still require time, patience, and effort if the producer is going to minimize the risk of failures in the wellbore. There are also important choices made after the wellbore is completed. High-pressure and sonic tests are available that allow producers to evaluate the integrity of the wellbore before hydraulic fracturing begins. If the cementing has not adhered adequately to the steel casing, for example, then additional techniques can be used to re-cement the well. But again, the careful implementation of these tests takes time, patience, and effort. A producer that works hard and applies these techniques judiciously is likely to avoid bad environmental outcomes; whereas a producer that is less careful runs a much higher risk.

2.2.2 Risks to Surface Water

Advanced drilling techniques also raise important concerns about surface water contamination. Hydraulic fracturing requires injecting large quantities of chemically treated water into the wellbore, and the fracking fluids that are used contain hundreds of different chemicals, some of which are toxic and hazardous to human health and the environment. Much of this water stays in the well or can be re-injected into the well after natural gas has been extracted. But the remaining wastewater must either be treated or stored on-site, increasing the probability of surface spills and introducing new risks that simply were not present in traditional drilling.

Wastewater is typically stored on-site in large surface pits lined with impermeable plastic, and then often loaded into tanker trucks. Making sure these pits are large enough, well-constructed, and well-maintained takes time, patience, and effort, as does transferring wastewater in and out of the pits and trucks. Moreover, constructing surface puts and maintaining a fleet of tanker trucks is expensive, so producers are constantly trading off operating cost against the private cost of environmental damages. Mistakes in handling wastewater potentially impose large environmental costs, particularly if it reaches a lake, river, or other surface water.[1]

With natural gas drilling there is also the risk of a blowout. Natural gas accumulations are highly pressurized. Blowout preventers and other pressure control equipment are designed to control natural gas as it exits the well, but equipment failure or operator error can lead to an uncontrolled release. This happens occasionally with oil drilling as well, as was recently witnessed with the British Petroleum Deepwater Horizon accident. Blowouts cause drilling fluids to be spewed over a wide area, causing widespread land contamination and potentially contaminating nearby surface water.[2]

[1] Olmstead, et al. (2013) perform an econometric analysis of the effect of shale gas development on surface water quality in Pennsylvania, finding evidence of increased pollution downstream from production locations.

[2] For example, in April 2011, there was a blowout in a natural gas well in northern Pennsylvania owned by Chesapeake Energy Corp. According to media reports, the well spewed drilling fluids and brine for more than twelve hours, leaking into the Susquehanna River, which flows into Chesapeake Bay (Associated Press 2012). The extent of environmental damages is still not well understood, but the accident underscores

Again, this is something that is at least partially driven by producer behavior because effective use and maintenance of pressure control equipment requires time and effort.

3 Policy Alternatives

The previous section makes it clear that prudent behavior by natural gas producers can reduce environmental risks substantially. Thus the challenge for policymakers is to design regulation that encourages producers to take these precautions when constructing and maintaining wells. There are costs associated with environmental damages and costs associated with producer time, effort, and capital. The "judgment proof problem" means, however, that in general there is insufficient incentive for producers to exercise care. This section examines the different regulatory approaches that are available for mitigating moral hazard. Much of this comes directly from the large existing literature in law and economics.

3.1 Tort System

One of the most common approaches for addressing environmental damages is the tort system. Anyone who has suffered a loss from a firm's actions can bring a claim in court for compensation. There is a broad history in the United States of firms being required to pay billions of dollars to compensate the victims of environmental damages. Most recently, British Petroleum was forced to pay billions of dollars in damages following the Deepwater Horizon rig explosion in April 2010 (Krauss and Schwartz, 2012).

In theory, the tort system could lead firms to internalize potential environmental damages. If firms face the risk of *ex post* penalties when damages occur, this should lead them to make choices *ex ante* which reduce the risk of damages. Brown (1973) describes the conditions under which strict liability leads agents to take *optimal* levels of care in equilibrium. If there is perfect information and the tort system works perfectly then

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the potential for blowouts to cause land and water contamination over a wide geographic area.

agents internalize all the costs of their actions, and thus make choices that minimize expected total social costs.

In practice, however, there are several important limitations with the tort system that mean that it falls short of this theoretical ideal (Shavell, 1984a, Shavell, 1984b, Shavell, 1986). First, firms will only internalize potential future damages if they will indeed be sued for any harm that is done. When there is a probability that they will not be sued, this *dilutes* the incentives for risk-reducing behavior. For example, high administrative and legal costs mean that not everyone who suffers from damages will indeed decide to sue. Moreover, if it is difficult to *attribute* damages to a particular firm this will reduce the probability of legal action.[3]

Another limitation with the tort system is that firms are not around forever. It may take many years before the environmental damages from natural gas production are realized. And by this time, the producers may no longer exist or may no longer have the resources to finance necessary cleanups or to compensate those who have been affected. This well-known "judgment proof problem" (Shavell, 1986) undermines the ability of the tort system to bring about the socially desirable level of risk-avoidance. Forward-looking producers know that they are unlikely to be around when damages are realized, so they underinvest in environmental protection.

Bankruptcy laws further insulate firms from potential damages. When potential damages exceed the total value of the company, the tort system provides an insufficient deterrent.[4] This is a realistic scenario with natural gas producers, both because the potential damages are large and because much of the drilling is performed by small and medium-sized companies. As with the other limitations of the tort system, the problem with bankruptcy protection is that it leads producers to choose higher risk practices than they would if they were responsible for the full costs of all potential environmental

[3] A substantial literature in law in economics examines the distinction between negligence and strict liability. Under a negligence rule, the firm would be liable only if it had failed to reach some standard for care. Strict liability, in contrast, is broader, and is a firm is liable for damages regardless of whether or not it was negligent. See Shavell (2004) pages 224-229 for a discussion of potential challenges in determining negligence.

[4] Pitchford (1995) shows that this is true even when a firm's creditors are also liable for environmental damages.

damage. In the extreme, a producer with no assets will have no liability-related incentive to exercise caution.

3.1.1 Market Structure

In evaluating the potential effectiveness of the tort system, it is important to take into account the market structure in natural gas production. This is relevant both for thinking about the probability with which companies will still exist once environmental damages are realized, and for evaluating bankruptcy protection. In the United States, most hydraulic fracturing is performed by small and medium-sized companies.[5] Figure 2 provides a visual description of market concentration in hydraulic fracturing compared to deepwater oil drilling. The area of the circles is proportional to the number of wells being drilled.

The figure makes clear that there are a large number of companies performing hydraulic fracturing in the United States. Although there are a few large producers, the market is relatively unconcentrated. The largest producer, XTO Energy Inc., has 9 percent of the market and the ten largest producers have only 41 percent of the market.[6] In contrast, deepwater oil drilling in the Gulf of Mexico is more concentrated. The largest producer as of March 2012 (Shell) has 24 percent of the market, and the ten largest producers have 78 percent of the market. Deepwater oil drilling is capital and technology intensive, and a limited number of producers worldwide have the level of sophistication necessary for these projects.

The presence of so many small and medium-sized firms in hydraulic fracturing raises serious concerns about the ability to finance environmental cleanups. After the Deepwater Horizon accident, British Petroleum immediately established a $20 billion fund from which to pay for the cleanup and to compensate individuals or groups that would be affected (Weisman and Chazan, 2012). Most companies that perform hydraulic

[5] In related research, Ringleb and Wiggins (1990) examine small-firm entry into the U.S. economy between 1967 and 1980, finding that small firms were more likely to enter sectors with more potential liability.
[6] Economists often use the Herfindahl Index (HHI) as a measure of market concentration. The HHI among these natural gas producers is 0.029, compared to 0.106 for deepwater oil drilling in the Gulf of Mexico.

fracturing do not have anywhere near this level of financial resources. It is relatively easy for small producers to enter and exit the market, and bankruptcy laws limit the liability of any producer to the total value of the company. A single severe accident for most of these producers would put them into bankruptcy, leaving the cleanup to be financed with public funds.

3.2 Direct Regulation

Another approach for addressing environmental damages is to use technology requirements and other forms of direct regulation. U.S. natural gas producers are subject to a wide range of direct regulations regarding, for example, site selection and preparation, well spacing rules, casing and cementing depth, and wastewater storage and disposal.

Direct regulation has several advantages relative to tort liability. Perhaps most importantly, the "judgment proof problem" is not a relevant for direct regulation because it works by restricting the set of *ex ante* choices available to producers. This is potentially quite an important advantage for direct regulation given the market structure in natural gas production. Shavell (1984b) also points out that *employee* liability may be different from firm liability. Regardless of whether the firm has a large amount of assets, an individual employee's personal liability is typically much smaller, potentially leading them not to take the appropriate level of risk reduction. In these cases, the tort system, by itself, is not going to eliminate the moral hazard problem so direct regulation may be an important alternative.

An important limitation with direct regulation is that it can be difficult to *enforce*. Natural gas production is geographically dispersed at thousands of sites in more than a dozen states and to have regulators at each location would be prohibitively expensive.[7] Advanced drilling techniques are also highly technical, requiring expert regulators. Regulators could be on a drilling site twenty-four hours a day, but if they do not

[7] Similar challenges are faced in offshore oil drilling. At the time of the BP Deepwater Horizon oil spill, there were only 60 federal inspectors for 4,000 drilling facilities in the Gulf of Mexico (Calmes and Cooper, 2010).

understand engineering and well construction then they are going to be of limited effectiveness. Moreover, there continues to be rapid technological innovation, so regulators need constant training to keep up with the industry. And if an engineer knows enough to be a good regulator, he or she will be highly valued by producers, and thus regulating agencies will be forced to compete with producers for top engineers.

This is related but different to the question of whether the producer or the regulator best understands the potential risks. Shavell (1984b) argues that a key determinant of the relative desirability of tort liability and direct regulation is the possibility of a "difference in knowledge about risky activities". Firms are often in a better position than the regulator to understand the costs and benefits of different choices, and tort liability has an advantage in these cases. In contrast, when the regulator knows more than the firm, direct regulation makes more sense. Although an argument could be made either way, with natural gas production there is at least some information that is better understood by the producer. Every drilling site has unique challenges and issues, and to expect regulators to correctly anticipate all possible environmental risks is unrealistic.

Direct regulation can also be very expensive for producers. Imposing one-size-fits-all requirements for well construction would substantially increase the cost of well construction. For example, one could require that high-pressure and sonic tests always used after well construction. These risk-mitigation techniques are an important part of the producers' toolkit and they can substantially reduce the risk of groundwater contamination. However, there are also real economic costs associated with using these techniques, and it would be expensive both in terms of capital expenditures and personnel expenditures to require that they be used universally. Economic efficiency requires that producers have a certain amount of discretion, and that they be allowed to use their experience to balance the tradeoff between well construction expenses and environmental protection.

In some cases, direct regulation is the only feasible regulatory approach. As mentioned in the introduction, air pollution and greenhouse gas emissions are fundamentally different from the other environmental risks because they cannot be observed *ex post*. For example, it is essentially impossible to determine after the fact how much methane has been released during well construction. This lack of observability makes it hard to imagine addressing these externalities with the tort system and policy does indeed seem to be heading toward direct regulation. For example, the EPA recently enacted minimum standards that will require natural gas producers to use methane capture equipment by 2015 (EPA, 2012).

3.3 Mandated Insurance

Another approach for addressing environmental damages is to require companies to buy insurance that covers the cost of clean-ups when accidents occur. There is a long history of using mandated insurance in energy markets. In 1989, the Exxon Valdez oil tanker struck a reef off Prince William Sound, Alaska, spilling millions gallons of crude oil. Following the spill, the *Oil Spill Liability Trust Fund* was established and funded through a tax on domestic and imported oil, currently 8 cents per barrel.[8] These funds go into a single communal fund that is available to help pay for damages when accidents occur. Mandated insurance also plays a role with nuclear power. All U.S. nuclear plants must buy a minimum level of accident insurance in private markets. This minimum amount has changed over time and is currently $375 million. There is also a second layer of joint insurance by which insurers agree to provide hundreds of millions in funds if a major accident occurs at any U.S. nuclear plant.

Insurance helps ensure that funds are available for clean-ups but it does not address the underlying moral hazard problem. Insurance *insulates* agents from the consequences of their actions, leading them to engage in riskier behavior than they would if they bore the full costs of adverse outcomes. Just like an insured motorist is going to be less careful driving, an insured natural gas producer is going to be less careful when deciding where and how to drill. Insurance does, however, help share risk between agents. This can be welfare improving particularly if agents are risk averse and do not have other mechanisms for spreading risks. This tradeoff between risk sharing and moral

[8] This legislation also set liability caps on oil producers that are not adjusted for inflation; the caps have decreased in value over time. These liability caps exacerbate moral hazard (Greenstone 2010).

hazard has long been recognized in the economics literature and in applications to environmental risks. See, e.g., Segerson (1989).

Mandated insurance increases incentives for firms to exercise care only if insurers can observe risk-reducing behavior (Shavell, 1984b). In many insurance markets, agents are rewarded for good behavior. For example, non-smokers often qualify for lower health insurance premiums than smokers. This distinction is possible because smoking is at least partly observable and verifiable. With perfect monitoring and a competitive insurance market, risk-adjusted premiums would reflect the expected damages associated with different behaviors, thereby mitigating the moral hazard problem. With natural gas production, however, monitoring is difficult and expensive. The monitoring and enforcement challenges described above for direct regulation also make it difficult for private insurers to efficiently categorize producers according to the choices they make and with one common insurance pool, producers have little incentive to engage in costly risk-reducing behavior.

Insurers can observe *ex post* outcomes even if they cannot observe *ex ante* behavior. Most insurers adjust premiums on the basis of prior claims. Car insurance premiums, for example, increase after an accident. Experience-rating can help reduce moral hazard because forward-looking agents take into account future premiums when making decisions. For natural gas producers, however, experience-rating is unlikely to substantially mitigate moral hazard. Environmental damages may take many years to be realized, and producers enter and exit the market frequently. Producers know that they are unlikely to be around for many years, and thus put less weight on future premiums. Moreover, after a severe accident a producer may simply choose to exit the market rather than pay increased premiums. Understanding these dynamics, private insurers will price this increased risk into premiums, which increases the cost of doing business for all producers but without increasing incentives for producers to exercise care.

Mandated insurance would make sense, however, when used jointly with other forms of regulation, helping to pay for the damages associated with catastrophic accidents. A hybrid plan might include bonding requirements up to a particular dollar amount, while also requiring producers to purchase insurance for damages that exceed the amount of the bond. Supporters of hydraulic fracturing argue that the risk of serious accidents is extremely low, so presumably premiums would be small. One could view a hybrid policy like this as an insurance policy with a high deductible. When accidents happen, the bond is used first, and insurance is brought in only after the bond has been exhausted. In this way, the bond acts as a deductible. With the bond in place the producer has some of its own money at stake, and increasing the producer's incentive to make good choices.

4 Bonding Requirements

This section turns to focus on bonding requirements. Although there are important limitations, bonding requirements are actually quite well-suited for many of the environmental risks in this market and can be a valuable complement to the other regulatory approaches. The section outlines current federal and state bonding requirements, discusses the costs and benefits of bonding, describes the different types of bonds that are available and explores the rationale behind "blanket" bonds and risk-adjusted minimum bond amounts.

4.1 Current Federal Requirements

Bonding requirements have played a role in the natural gas market for over 90 years. Since the Mineral Leasing Act of 1920, natural gas producers in the United States have been required to post a bond with the U.S. Bureau of Land Management (BLM) prior to drilling on federal lands. These bonds were primarily designed to ensure that producers fulfill their obligations to clean up the drilling site after production was completed, though funds can also be used to pay for environmental clean-ups, if necessary.

From the beginning, this legislation has been aimed at addressing moral hazard. When drilling results in no significant environmental damage and producers adequately reclaim the drilling site, then the producer receives the bond back in entirety along with accrued interest. It is only when problems occur that the bond is in jeopardy. This makes bonds very different from insurance. When a company pays an insurance premium, this money is gone forever, regardless of what happens. In contrast, a bond is the producer's own money at stake, which increases the incentive to act prudently.

The Mineral Leasing Act and its subsequent revisions establish a federal minimum bond amount of $10,000 for an individual lease on federal lands (Table 1). On average there are about five wells per lease, which implies a minimum bond per well of $2,000. This dollar amount was set in 1960 and has never been updated for inflation.[9] Alternatively, producers can post blanket bonds that cover all wells within a given state or even nationwide. A producer can post a $25,000 bond to cover all of the leases in a given state, or $150,000 to cover all leases in all states. These dollar amounts for blanket bonds were set in 1951 and have never been updated for inflation.

Federal and state laws determine what happens when there are changes in well ownership. Bonds stay with wells and not with producers, so when a well is sold, the ownership of the bond transfers at the same time, and there is no lapse in bond coverage. In cases of bankruptcy, the bonds cannot be used to pay generic company debts until such time that the funds are returned according to the normal rules for returning bonds— after a well has finished production. With natural gas wells, production declines quickly after a well is first constructed, but most wells continue to produce at least a small amount of natural gas for many years. When production is completed, the BLM inspects the site and verifies that reclamation efforts have been successful.

4.2 Current State Requirements

About one-quarter of hydraulic fracturing occurs on federal land under the jurisdiction of the BLM.[10] The remainder occurs on land under the jurisdiction of states. Many states have bonding requirements for natural gas producers that exceed the minimum federal requirements. See Table 2. State-level requirements extend bonding

[9] The fact that these minimum bond amounts have not been adjusted for inflation means that their real value has eroded substantially. Since 1961, prices have increased about six-fold, so adjusting for inflation would increase the minimum bond amount from to $10,000 to about $60,000.

[10] Baird Equity Research, quoted in Tennile (2012).

requirements to drilling on non-federal lands, and in most cases increase the required bond amounts above the federal minimum levels (GAO 2010). There is a great deal of heterogeneity across states in bonding requirements. Most states have both bonds for individual wells and blanket bonds, but the size of the bonds varies widely. The minimum dollar amount for individual bonds, for example, ranges from $500 (Kentucky) to $100,000 (Alaska). In addition, some states determine the minimum bond amount based on the depth of the well, or other proxies for environmental risk.

Several states have recently increased bonding requirements, while several others are actively considering changes. The West Virginia Legislature passed a bill in December 2011 that establishes a $50,000 bond requirement per well, and a $250,000 blanket bond for all of a producer's wells in the state.[11] The Maryland legislature recently considered a bill that would have increased the minimum required bond per well to $50,000 and eliminated blanket bonds. New York State has a maximum bond amount per deep well of $250,000, the highest maximum bond amount for any state. In addition to stringent water-use restrictions, this requirement has effectively created a moratorium on hydraulic fracturing. The only state that has an explicit moratorium is Vermont, which instituted legislation banning hydraulic fracturing in May 2012, although Vermont has few if any known reserves (Gram 2012).

4.3 The Rationale for Bonding Requirements

Bonding requirements increase the incentive for natural gas producers to act prudently with regard to environmental risks. This could include, for example, choosing drilling locations with lower potential environmental damages or exercising additional care when casing and cementing a well. Bonding requirements help address moral hazard by forcing producers to take potential external damages into account. A producer that avoids environmental damages stands to get back the entire bond, and so the producer takes this into account when making choices.

[11] West Virginia Legislature H.B. 401, §22-6A-15. "Performance Bonds: Corporate Surety or Other Security," December 2011.

Bonding is most effective when there are a small number of contracting parties, a well-defined time horizon, well-defined definitions of non-compliance, and a high probability of detecting non-compliance (Gerard and Wilson, 2009). Natural gas drilling is a good fit along these dimensions, particularly with regard to highly visible damages such as surface spills and blowouts. Groundwater contamination is less visible and takes longer to detect, making it more difficult to address not just with bonding requirements, but also through the tort system and via mandated insurance.

Bonding is also well-suited for ensuring site remediation. When production has been completed, it is important that the well be "plugged" to avoid contamination of groundwater through the wellbore. Producers are also required to remove all equipment and restore the land to the extent possible to its original condition. Ensuring regulatory compliance with these end-of-life requirements can be difficult, however, because production occurs over many years. By the time it becomes necessary to plug the well the producer that originally drilled the well may be "judgment proof", either because it no longer exists, or because it does not have the funds necessary to finance remediation.

Bonding requirements provide a source of funds for site remediation, but they also encourage *ex ante* behavior to reduce these costs. In the United States there are tens of thousands of abandoned oil and gas wells. According to GAO (2010), the average cost of reclaiming these sites is about $13,000 per well. However, the *range* of costs is enormous, from under $1,000 to more than $500,000 depending on the degree to which the land has been disturbed, and the depth and characteristics of the well. Bonding requirements encourage producers to internalize these future costs and, for example, to choose locations where the costs of end-of-life remediation tend to be lower.

4.4 The Costs of Bonding Requirements

Bonding requirements also have a number of important limitations. Probably most importantly, bonding imposes real costs on producers because it ties up their operating capital. Producers can typically post bonds using their choice of low-risk assets including certificates of deposit and Treasury securities. So the opportunity cost of tying up the producers' operating capital is the *difference* in the rate of return between this low-risk asset and the rate of return where the producer would have otherwise had this capital.

These costs vary widely across producers depending on their size and access to credit. For a large producer with a substantial cash reserve, the cost is small because the opportunity cost of capital is low. Many producers, however, are net debtors with a cost of capital substantially higher than the risk-free rate. For these producers, the bonding requirement imposes a cost equal to the difference between their cost of capital and the risk-free rate.

Moreover, if the bond amount is large enough, it may actually increase the producers' cost of capital. Bonds are liabilities that appear on producers' balance sheets, potentially impacting their ability to access credit. These costs are largest for small and medium-sized producers and/or for any producer who already had limited access to credit. For more on liquidity constraints and the economic costs of bonding requirements see Shogren, Herriges, and Goviandasamy (1993), Boyd (2001) and Mitchell and Casman (2011).

There are also transaction costs, monitoring costs, and administrative costs associated with bonding requirements. These costs are borne by both producers and regulators. Some of these costs are fixed costs per well (or per bond) and some of these costs scale with the amount of the bond. In general, the more complex the regulatory commitments ensured by the bond, the higher these costs will be (Gerard, 2000). At the same time, it is also important to point out that these costs are not unique to bonding. The tort system, direct regulation, and mandated insurance all have additional costs that must be taken into account when comparing the effectiveness of alternative regulatory approaches (Shavell, 2004).

The fact that bonding requirements impose all these economic costs means that optimal bond amounts will necessarily be less than maximum potential damages (Gerard and Wilson, 2009). This is a general result in economic analyses of bonding requirements, and is particularly the case for natural gas producers given that the distribution of damages has a long right tail. Although most drilling projects yield relatively modest damages, there is also a small probability of catastrophic damage. Contamination of a large source of drinking water, for example, could impose hundreds of millions of dollars in damages. Setting the bond amount equal to the *maximum* potential environmental damage would completely eliminate moral hazard, but at such a high cost to producers that the total cost would exceed the total benefit.

The optimal bond amount equates the *marginal* benefit of a higher bond against the *marginal* cost. Determining the optimal bond amount is a challenging exercise that goes beyond the scope of this discussion. One needs to know the entire distribution of potential external damages, but also the *elasticity* of expected damages with regard to the bond amount. Both of these objects are difficult to observe empirically, particularly given that drilling techniques are evolving rapidly so these parameters are changing over time. One also needs to know the producers' cost of capital, the length of the project, and administrative costs. See Gerard (2000) for a conceptual framework and additional details.

4.5 Additional Considerations for Bonding Requirements

4.5.1 Types of Bonds

Under current federal legislation, bonds must be one of two types: a personal bond or a surety bond. To date, existing bonds have fallen about equally in both categories (GAO 2010). With a personal bond the producer deposits the required amount of financial assets with the BLM. Personal bonds can take the form of low-risk assets such as certificates of deposit or negotiable U.S. Treasury securities. Thus the producer earns interest on the bond year after year and if the market value of the asset ever falls below the required minimum level, the producer is required to pledge additional assets.

In contrast, a surety bond is a third-party guarantee that the producer purchases from an insurance company. If there are no environmental damages, then the insurance company pays nothing. Surety bonds are typically "experience-rated", so a producer that has a good record of environmental protection pays lower premiums. This experience rating helps mitigate the misalignment of incentives because a forward-looking producer takes into account potential changes in premium levels when making decisions that affect the environment. Nonetheless, as we discussed earlier, experience-rating is unlikely to eliminate moral hazard in this market. From the perspective of reducing moral hazard, these two types of bonds are very different. Personal bonds mitigate moral hazard, because the producer has more of its own assets at risk whereas surety bonds should be viewed more like mandated insurance.

4.5.2 Blanket Bonds

The economic argument for blanket bonds is that if the total number of wells operated by a company is reasonably low, then blanket bonds can increase incentives for prudent environmental stewardship. When environmental damages occur, producers stand to risk the entire blanket bond. Thus, a natural gas producer that owns a small number of wells and meets bonding requirements using a blanket bond has more incentive than other producers to make choices that protect the environment.

Of course, some companies own hundreds or even thousands of wells. Consider, for example, a hypothetical company that owns 500 wells and has satisfied the federal bonding requirement by posting a blanket bond of $1 million. The average bond amount per well in this case would be $2,000, too low to finance routine site reclamation expenses.[12] Even though the industry is relatively unconcentrated, with 18,000 development wells drilled annually in the United States, many companies end up with unreasonably low bond amounts per well under blanket bond provisions.

In the past, this has led to situations in which the available blanket bond was inadequate to pay for necessary cleanups on multiple sites (GAO 2010). For example, in 2001, the Emerald Restoration and Production Company went bankrupt, leaving behind 120 wells that needed to be plugged and the sites reclaimed. The company had posted a $125,000 bond, but this was not nearly enough to pay for expected expenses. To date more than $2 million has been used in public funds for this cleanup, and additional expenses are expected (Oil and Gas Accountability Project 2005).

[12] GAO (2010), p. 16, reports an average cost of site reclamation per well of $12,788 per well.

4.5.3 Incorporating Observable Measures of Risk

Some states' minimum bond amounts depend on an observable measure of the level of risk. For example, Texas sets bond amounts according to the depth of the well. The economic argument for using more categories is that different well types have different levels of environmental risk. For example, deeper wells tend to be riskier. Natural gas accumulations at lower depths are at higher pressure levels, and thus more can go wrong, with more significant consequences, during well construction. Having more categories allows for lower bonds on wells where the risks are smaller and using richer formulas for required minimum bond levels also has the advantage of minimizing distortions in producer decisions about what type of wells to drill.

Although the economic argument is reasonable, deciding exactly which criteria to use is difficult. With depth, for example, there is a counter argument. Whereas deeper wells are under more pressure, shallow wells present risks because hydraulic fracturing occurs closer to groundwater reserves. And for every categorization that a policymaker includes there will be exceptions. Some deep wells are relatively safe because, for example, they are in locations far from populated areas and water resources whereas some shallow wells are quite risky because of nearby groundwater reserves or some other characteristic.

An advantage of the current federal system, which does not distinguish by depth or other measures of risk, is that it is easy to administer. In contrast, many states allow for substantial discretion in setting bond amounts. In theory, negotiating bond amounts on a well-by-well basis could lead to more efficient bond amounts. The problem with this in practice is that it adds to the overall economic cost of bonding requirements, causing resources to be directed toward non-productive uses such as negotiating with regulators over bond amounts.

5 Concluding Comments

The immense supply of natural gas made possible by hydraulic fracturing offers enormous potential benefits. The challenge for policymakers is how to facilitate the continued development of these valuable resources while ensuring environmentally safe drilling and adequate site reclamation once production has been completed. This is particularly difficult in this market because natural gas production occurs at thousands of geographically dispersed wells, making direct monitoring extremely expensive and raising important questions about moral hazard.

This article reviews the available regulatory approaches for mitigating moral hazard in this sector. Tort liability, direct regulation, and mandated insurance are all likely to continue playing a role in the evolving federal and state regulatory systems. This article highlights bonding requirements as a valuable complement to these approaches. Bonds provide a source of funds for cleanups when necessary, but, more importantly, provide an incentive for producers to exert effort toward avoiding environmental damages altogether. Bonding requirements are also particularly well-suited for ensuring that private funds are available to pay for site reclamation.

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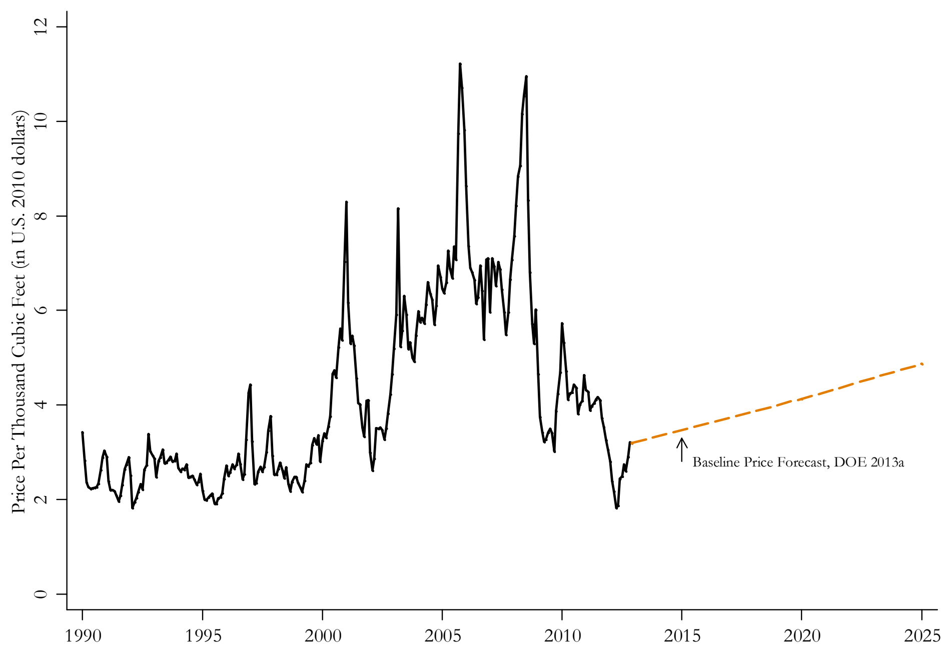
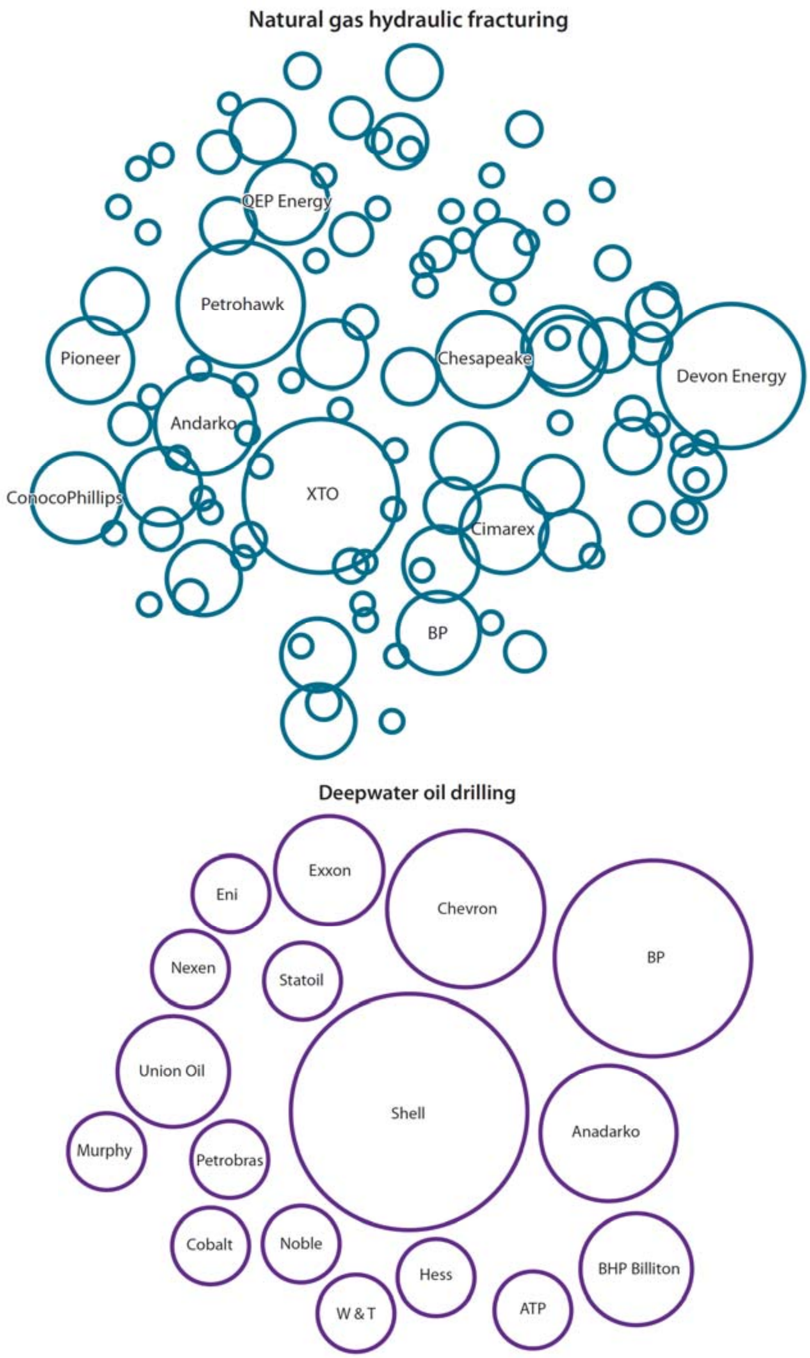
Figure 1: Natural Gas Prices 1990-2012



Source: Author's tabulation based on data from U.S. Department of Energy (2011, 2013a).

Figure 2: Market Concentration



Note: This figure describes market concentration in natural gas hydraulic fracturing and deepwater oil drilling. The figure was constructed by the author using data on active drilling operations from *SmithBits* "U.S. Weekly Rig Detail Report" for March 23, 2012 and *Bureau of Ocean Energy Management, Regulation and Enforcement*, *Current Deepwater Activity" for April 2, 2012. See Kellogg (2011) for discussion of the *SmithBits* data. To focus on hydraulic fracturing we restricted the sample to all horizontal and directional development wells for natural gas with a target depth in excess of 5000 feet, leaving 442 total wells being produced by 104 producers. The area of the circles is proportional to the number of wells being drilled.

TABLE 1
Existing Minimum Bonding Requirements for Drilling on Federal Lands

	Minimum Bonding Requirement Required by Federal Law:
Per Lease	$10,000
Blanket Bonds	
Statewide	$25,000
Nationwide	$150,000
Average number of wells per lease	5.3

Source: GAO (2010).

TABLE 2

Existing State Bonding Requirements and the Growth of Proven Shale Reserves

State	Bond Amount Depends on Well Depth	Minimum Bond Amount Per Well ($)	Blanket Bond Amounts ($)
Alabama	Y	5,000-50,000	100,000
Alaska	N	100,000	200,000
Arizona	Y	10,000-20,000	25,000-250,000
Arkansas	n.s.	Not to exceed $100,000	n.s.
California	Y	15,000-30,000	100,000-1,000,000
Colorado	Y	10,000-20,000	60,000-100,000
Delaware	N	n.s.	n.s.
Florida	Y	50,000-200,000	1,000,000
Georgia	N	not to exceed $50,000	50,000
Idaho	N	10,000	25,000
Illinois	Y	1,500-3,000	25,000-100,000
Indiana	N	2,500	45,000
Kansas	Y	7,500-30,000	30,000-45,000
Kentucky	Y	500-5,000	10,000-100,000
Louisiana	N	n.s.	n.s.
Maryland	N	Not to exceed 100,000	Not to exceed 500,000
Michigan	Y	10,000-30,000	100,000-250,000
Mississippi	Y	10,000-50,000	100,000
Missouri	Y	1,000-4,000	20,000-30,000
Montana	Y	1,500-10,000	50,000
Nebraska	N	5,000	25,000
Nevada	N	10,000	50,000
New Mexico	Y	5,000-12,500	50,000
New York	Y	2,500-250,000	25,000-2,000,000
North Carolina	Y	5,000 + 1 dollar per foot	n.s.
North Dakota	N	50,000	100,000
Ohio	N	5,000	15,000
Oklahoma	N	Plugging cost	25,000-50,000
Oregon	Y	10,000-25,000	100,000-no limit
Pennsylvania	Y	Varies	250,000-600,000
South Dakota	N	5,000	20,000
Tennessee	N	2,000	10,000
Texas	Y	2 dollars per foot	25,000-250,000
Utah	Y	1,500-60,000	15,000-120,000
Virginia	N	10,000	25,000-100,000
Washington	N	Not less than 50,000	Not less than 250,000
West Virginia	N	50,000	250,000
Wyoming	Y	10,000-20,000	75,000

Source: GAO (2010); Groundwater Protection Council n.d.; Pennsylvania Legislature, H.B. 1950, §3225; West Virginia Legislature H.B. 401, §22-6A-15.; Maryland Department of Energy, n.d.. See also Gerard and Wilson (2009) for additional discussion of bonding requirements in California, Texas, and Illinois.